International Journal of Robotics
Research and Development (IJRRD)
ISSN(P): 2250-1592; ISSN(E): 2278-9421
Vol. 11, Issue 2, Dec 2021, 19–38

REVIEW: THE RE-CONFIGURABLE ROBOTIC GRIPPER DESIGN, DYNAMICS, AND CONTROL

AHMED KH AHMED[1], SAFEEN YASEEN EZDEEN[2] & AHMAD MOHAMAD SINJARI[3]

[1,2] *Electrical Engineering Department, Salahadin University -Erbil, ERBIL, 44001, IRAQ*

[3] *Mechanical Engineering, Salahadin University -Erbil, ERBIL, 44001, IRAQ*

ABSTRACT

The manipulator robots are devices used to perform dangerous tasks and impossible missions that humans cannot perform without paying too much effort and time. Therefore, they are used in a wide range of applications without any interaction with humans. This type of robot can carry different types of end-effectors to perform various kinds of applications. According to the Application, the robot end-effector types can be applied to perform the task accurately. Grippers are mainly used for grasping. The grasping process can be defined as the act of holding objects. One of the essential types of grippers is the re-configurable type. This type of gripper is very excited because of its adaptation and reconfigurability features that they have. The problem of grasping different objects with different shapes and geometries is a crucial enigma. When the manipulators are utilized to automate the tasks in industrial plants, the gripper tool is changed according to the application requirement, which will cause longer cycle times and more expensive grippers. The possibility of having a gripper that adapts to the applications without changing it is significant in reducing the time and cost of manufacturing. This paper will review the studies conducted around re-configurable grippers and classify the literature based on the number of fingers. Many critical parameters, objectives, structural and mechanisms of the re-configurable grippers will be presented separately using tables for each class. We proposed a new type of re-configurable gripper to be studied, and it will be the axis of the subsequent research.

KEYWORDS: Gripper, Re-Configurable, Robot, End-Effector & Grasping Tool

Received: Jul 28 2021; **Accepted**: Aug 18, 2021; **Published**: Sep 07, 2021; **Paper Id.**: IJRRDDEC20212

Original Article

1. INTRODUCTION

Robot manipulators are an appropriate and valuable tool that is becoming very popular in industries and exciting for researchers, engineers, and clinicians. Many definitions were proposed for mechanical manipulations, but in general, mechanical manipulators are defined as the act of applying force on an object, causing motion or deformation. One of the tasks that manipulators can do is grasping. Grasping may be defined as the process of holding objects. The gripping task can be performed by grippers, which can be attached to the manipulators' end-effector. Different characteristics of the object and manipulator decide which type of grippers is appropriate for this specific task. Some grippers are designed to be used in many applications and grasp different geometric shapes [1].

The grippers are of different shapes, sizes, classes, and configurations. For example, according to the number of fingers, One-finger, Two-finger, Three-finger, Four-finger, Flexible finger, Adaptive (re-configurable) multi-finger, Grain-Filled Flexible Ball, Bellows, and O-ring are some types of grippers [1–7]. Moreover, the gripper's actuation process is crucial because it represents the part that makes the gripping possible. Therefore, according to the actuation mechanism, the grippers can be classified as (Cable-based grippers, Vacuum-based grippers, Pneumatic-based grippers, Hydraulic-based grippers, Grippers based on the Electric-Servo.

General gripper applications are Assistive applications, Surgical Applications, Industrial Applications, and Applications for underwater. Furthermore, the grippers may be designed in many sizes and shapes according to the application requirement. For example, in surgical applications, micro-size grippers with the accuracy of hundreds of micrometers are used. On the other hand, big-size grippers are more efficient and widely used [1].

According to the material's stiffness, the grippers can be classified into two types, rigid and soft grippers. More details can be found in [1]. In the above section, many types of robotic grippers were presented, and in the literature of this field, different designs and techniques were presented and studied.

However, the most crucial type is the re-configurable type grippers. This type of grippers is interested mainly in innovative industries, manufacturing, and limp material handling. Besides the re-configurable properties of these grippers, they can also be cost-effective, lightweight, and robust. The most crucial advantage is that this type of grippers can be used for different object grasping without changing the tool, reducing the time wasted in changing the end-effector when the application requested is changed [8].

2. RE-CONFIGURABLE GRIPPERS

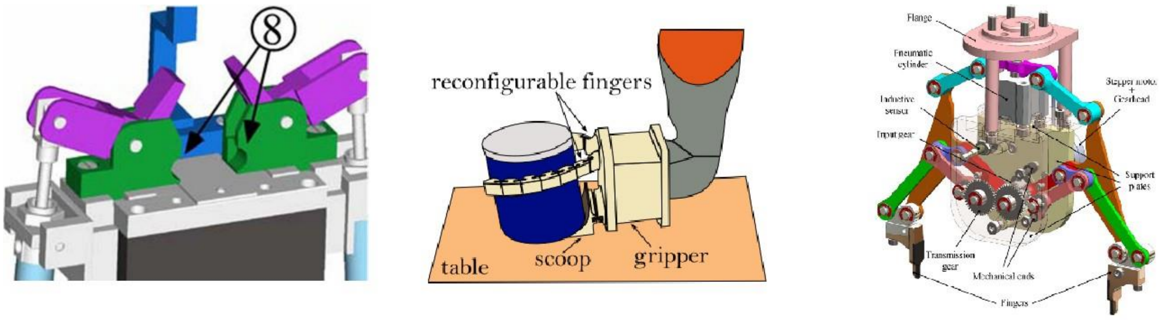
In manufacturing and production plants, manipulation and assembling are among the main tasks; this process is repeated each cycle of time as a manual and automatic procedure. These processes are optimized to increase productivity. However, when the manufacturer decided to mix up the assembly of different products or different models of the same product, this will dramatically increase the complexity of the process.

The problem of grasping different objects of different sizes, geometry, and shapes can be solved by increasing the system's configurability. The gripper with a reconfigurability feature is called a "re-configurable gripper." In the literature of the re-configurable grippers, a group of researchers focused on designing, analyzing, simulating, prototyping, and physically implementing different types of grippers to solve different manufacturing or grasping operation issues in the industries. During the past twenty-four years, twenty-seven researches were performed in this field. This review will summarize the literature by categorizing according to the gripper number of fingers.

2.1 Two-Finger Re-Configurable Grippers

For the assembly and disassembly of washing machine components, a high degree of freedom re-configurable gripper for grasping cylindrical and prismatic shaped parts within dimensional ranges typical of the washing machines' components studied by Molfino, Razzoli, and Zoppi [9]. The gripper is shown in Figure 1, (a) consists of two movable fingers, and one finger (stop finger) is used to determine the position of the grasped object in the direction orthogonal to the plane of the fingers. The two moving fingers are providing the force-closure grasp fingers translate symmetrically concerning the body of the gripper. For controlling the gripper, the fuzzy logic controller is used to adapting the gain of the gripper control system based on the feedback from the force sensors fixed on the fingers. Moreover, for robust grasping in unstructured

environments, highly adaptable and versatile hands are required with good and suitable strategies. To achieve this goal, (Turco et al., 2021) presented a method to grasp objects using a re-configurable soft gripper soft Scoop Gripper SSG, Figure 1, (b). The robust grasping is achieved using the scoop grasp strategy. The scoop is used to slide between the object and the surface on which the object is placed. The fingers are first configured according to the object geometry, and then it is used to establish a contact point with the object and grasp. The scoop grasp strategy will be calculated on an algorithm before sliding the scoop under the object and the flat surface. Experiments were performed to confirm the effectiveness of the proposed grasping method [10].



(a) (b) (c)

Figure 1: Two-Finger Re-Configurable griPpers, (a) Two-Finger Re-Configurable Gripper with stop Finger. Moreover, (b) Is the Two-Finger Re-Configurable Gripper with Scoop Support, Finally (c) Is the Two-finger Variable Aperture Gripper.

Furthermore, a variable aperture and cost-effective end effector are presented in (Rosati, Minto, and Oscari, 2017) work. As a result, the gripper in Figure 1, (c) can change the grasping width (aperture) to different grasping needs without affecting the working cycle time of the production system. The mechanisms used are two; one is an electrically actuated mechanism, which provides flexibility and adjusting the aperture. The second one is a pneumatic actuating mechanism used for high-speed open and close operation. The simulations and tests showed that the design effectively increases flexibility and reduces the cycle time in the production system. Table (1) shows more details about the grippers discussed above [8].

2.2 Three-Pin/Finger Re-Configurable Grippers

Sudsang, Srinivasa and Ponce, addressed manipulating and grasping three-dimensional objects utilizing a re-configurable gripper. The gripper in Figure 2 (a) is equipped with two parallel plates with adjustable distances by actuators. The computer controls the actuators. The gripper structure from the bottom is a bare plane, and from the top, it consists of a rectangular grid of actuated pins that can be controlled using computer control. Thus, the objects can be grasped using three pins and the bottom plate. First, the gripper prototype and the gripper design were described, then the simulation results and experiments were reported [11,12].

In Cavallo studies, a re-configurable three-finger gripper for grasping limp sheets was designed. The design proposes that the gripper firmly hold multipoint grasping and peaceful transfer of the limp sheets to the sorting buffers in the shoemaking process factory. The study investigated a mechatronic device

Table 1: The Overview of the Two-Finger Re-configurable Grippers

Authors	Applications / Aims	The Operating Mechanism Of The Fingers	Important Parameters
[9]	It is used for assembling and disassembling washing machine components.	The fingers actuated by driving pistons (pneumatic cylinder).	• Low cost. • The gripper is three DOFs. • It consists of two fingers with the third stop finger. • Adaptable for grasping cylindrical and prismatic shapes. • Fuzzy logic controller utilized to adapt the gain of the gripper.
[10]	Used for grasping in unstructured environments	They are composed of two soft fingers with tendon driven differential system actuated by motors.	• Two soft finger uses a scoop constrain to grasp objects. • Pre-grasp configuration Calculated using point cloud algorithm. • RGB-D camera used for detecting objects. • Different grasping success rates are 75%, up to 85 %. • When the weight of the object increases, the success rate is decreased dramatically.
[8]	Design of variable aperture end effector to grasp different handling demands.	Each finger is a four-bar linkage structure.	• Variable aperture. • Cost-effective. • Flexible. • High performance. • The aperture is adaptable. • Its low mass, inertia, and compact. • Aperture repetition accuracy is less or equal to 0.1 seconds. • The closing time of the jaws is less than or equal to 0.1 seconds. • The grasping force is larger or equal to 50 N. • Capable of grasping masses up to 5 kg.

capable of a multipoint grasp of one-layer leather sheets and firm hold. The four degrees of freedom gripper in Figure 2 (b) consists of three brackets with two phalanxes and suction cups at each finger's end. The design utilized motors for the actuation and a suction cup for grasping force. Two fingers will be moving and will be adjusted, and the third one is fixed. The steps for implementing this study are; the shape of the sheet will be analyzed, and then the pickup points will be calculated. Next, the finger size, torque for each phalanx, and the motor will be estimated. Then the structural and dynamic analysis will be performed [13,14].

Yeung and Mills addressed the six degrees of freedom re-configurable gripper design, development, and the description based on Flexible Fixtureless Assembly. With the help of the Flexible Fixtureless Assembly technique, the traditional fixtures in automotive body assembly were replaced by robots with multi-finger to grasp different parts precisely

and holding the parts in space rigidly, then locating the grasped part for the assembly. This work is based on three-finger gripper development. Each finger is with two joints and two contact points for grasping. For simulating the deflection of the gripper parts underwork, the finite element method is used. The gripper in Figure 2 (c) was fabricated and tested to achieve the study's objectives. The degree of freedom is chosen to be six with twelve independent contact forces. The kinematic design is decided to be three fingers with configurable arrangements [15,16].

Ragunathan and Karunamoorthy presented an innovative gripper developed within the EUROShoE project. In Figure 2 (h), the prehensor can do multipoint grasping, firm hold, and gentle transfer of limp materials. In addition, the design features are low inertia, modularity, and flexibility. The prehensor is three fingers of two degrees of freedom articulated mechanism. Each finger with four picking modules, and two of the fingers are movable and attached to the carpus of the prehensor while the middle one is fixed to the wrist. Two motors provide the rotation of the fingers around the vertical axes of the prehensor [17].

In (Canali et al., 2014) and (Canali et al., 2017), a general-purpose, two degrees of freedom robotic gripper for industrial manufacturing applications with adaptability for different objects and shapes were discussed. The gripper design is modular, and each finger has the same mechanical design, electronics, and control. Therefore, it is easy to equip the gripper with two, three, and even more fingers. Thus, the gripper mechanism Figure 2 (d) is equipped with three fingers, two on the left, right side and one on the middle of the prototype [18,19]. Besides, for the steps of structural, kinematics, and CAD synthesis and analysis of a re-configurable gripper having three fingers presented in (Staretu and Jitariu, 2015) see Figure 2 (e). Thus, it is demonstrated that three-finger grippers have four main configurations. ADAMS software was used to validate the operation, CAD simulation was performed and dynamically tested the gripper. The fingers are articulated bars, which provide good gripping and safer operation than wires and rollers [20,21].

Additionally, the design of a robotic gripper for industrial tasks is presented (Li et al., 2015). The gripper in Figure 2 (f) can grasp different objects of different sizes. The gripper is multi-degree of freedom with three fingers. Each finger has three joints that can be moved with the help of two motors, and every finger can be controlled independently. The gripper parts are palm, three fingers, rotating base. The first and second phalanges are coupled and driven by the first motor. The second motor rotates the fingers using a worm and wheel beside the third joint of the finger. The third degree of freedom of the fingers is not coupled; therefore, the configurability of the gripper can be achieved easily. The final configuration of the gripper can be determined based on the data from potentiometer sensors which sense the rotation angels of the fingers [22].

A high-speed multi-fingered and re-configurable gripper was presented in (Spiliotopoulos, Michalos, and Makris's, 2018) study. The work aims to develop an end effector, making it possible to hold different shapes and weights objects. The gripper in Figure 2 (i) is three fingers with eight degrees of freedom. The design, control, and re-configurable aspects of the gripper are presented in the work. The gripper has been tested, and different grasping modes, such as pinching and enclosing, have been executed successfully [23].

(Wan et al., 2020) proposed the learning method reconfiguring robotic grippers for grasping using a soft structure Omni-directional adaptation (see Figure 2 (g)). The proposed gripper in the study is re-configurable in terms of the number and arrangements of the gripper fingers. The learning method is used to find the outcome of each configuration and the effectiveness of the arrangement. The results show that the three-finger radial arrangement has a 96% grasp success rate. Also, the four-finger radial configuration can be applied in cases that require larger payloads with even distribution. The gripper can be equipped with two, three, or four fingers of Omni-adaptive types, and the fingers are driven by one

pneumatic input during the operation [24].

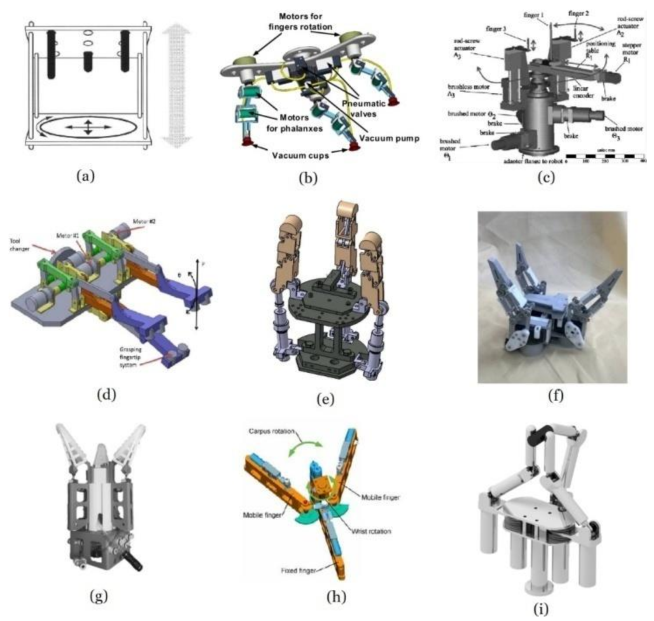


Figure 2: Some Examples of Three Pins/Fingers Re-Configurable Grippers.

The three pins/fingers mentioned above have more essential parameters summarized in Table 2.

2.4 Four Arm/Bar/Finger Re-Configurable Grippers

A multi-degree robotic gripper's suction and position control were first discussed (Tsourveloudis et al., 1999). The suction cup is mounted on the four arms with a crossbar configuration. Moreover, the fuzzy logic controller controls the generated suction and controls the position's suction units. The gripper in figure 3 (a) is mounted on a commercial manipulator to automate limp material handling. This robotic gripper can manipulate single and multiple panels of varying shapes and sizes without material distortion, deformation, or folding. The control structure consists of (Gripper system, robot arm, and suction control). Camera vision is used to detect the coming sheets and calculate the center of the gravity of the panel and the second moment of inertia. The system utilizes two Compu-motor AT-6400 microprocessor-based 4- axes indexers that are integrated with an IBM Workstation. Simulation results obtained using MATLAB'S SIMULINK simulation software find that all four suction cups reach their respective desired set points without any significant overshoot or error [25]. An identical study is also conducted in [26].

Table 2: The Overview of the Three-Pins /Fingers Re-Configurable Grippers

Authors	Applications / Aims	The Operating Mechanism of the Fingers	Important Parameters
[11,12]	To immobilize objects through frictionless contacts with three of the pins and the bottom plate.	The three pins' position on the top plate can be adjusted using computer control, and the objects can be grasped using both the top and bottom plate, which is an empty plate.	• The top plate holds a rectangular grid of actuated pins. • Each pin can be actuated separately. • Each pin is mounted with a load cell sensor to measure the axial force on the pin. • The top and lower plates can be moved relative to each other using a large actuator. • The lower plate is three degrees of freedom. • Lema 2 algorithm is used for computer control and grasp planning.
[13] and [14]	Used to multipoint grasp, firm hold, and gentle transfer of limp sheets to the sorting buffers before feeding the assembly sections.	The three fingers consist of two phalanxes each, and at the end of each finger, a suction cup is mounted for grasping. The fingers actuated using two motors for each finger.	• Two phalanxes for each finger. • Two motors are used for each finger actuation. • The gripper uses a total of three fingers. • The finger assembly is motorized in order to be rotated. • At the end of each finger, a suction cup is mounted for grasping limp materials. • The gripper has nine degrees of freedom.
[15,16]	For the implementation of robot-based Flexible Fixtureless Assembly to grasp and assemble parts.	The gripper is composed of three independent fingers, which allow independent motion concerning each other. The type of actuator used in each joint is an electro-mechanical actuator due to the torque output and positional accuracy.	• For part grasping, two movable joints and two contact points were provided for each finger. • The gripper is movable within 250 x 250 x 150 mm volume with $\mp$ 0.5 accuracies of positioning. • The gripper has six degrees of freedom. • Each finger has a power-off brake motor. • A linear encoder is used for linear axes. • Motion controllers are used to controlling the motion of the gripper. • I-DEAS software used for design, modeling, drafting, and Finite Element Analysis simulation.

[17]	To grasp, hold, and safe transfer of limp materials in the shoe industry.	Three fingers articulated mechanism with one finger fixed to the carpus, and two fingers are rotating symmetrically. Each finger carries four picking modules. The carpus is connecting to the base of the prehensor through revolute joints. The recovery works employing springs.	• Low inertia. • High modularity. • Full flexibility. • Adaptable. • High MTBF. • 5 KG Max mass. • High acceleration and velocity. • Two degrees of freedom. • Pneumatic vacuum pick modules.
[18,19]	To design a gripper with high flexibility and speed for industrial manufacturing.	The Three-finger mechanism is composed of two degrees of freedom for each finger. Electrical motors actuate the finger.	• It is two degrees of freedom per finger. • Simple kinematics. • Grasp size from 100 mm up to 1000 mm. • Grasp weights from 10 grams up to 10 kg. • Force and proximity sensors are Integrated. • Motors controlled by Elmo whistle via CAN bus and PC104. • ROS for communicating between the gripper and the robot.
[21]	To design a re-configurable modular anthropomorphic gripper with three fingers.	The fingers are articulated mechanisms with three phalanxes and two quadrilateral anti-parallelogram mechanisms. The mechanism is actuated by a slider rocker using a pneumatic linear motor.	• Four main configurations can be achieved. • The operation was verified using CAD simulation. • The dynamic behavior was verified using ADAMS software. • Low price.
[22]	The Three finger re-configurable gripper was designed for industrial tasks.	The fingers have three joints that are actuated by two motors with a four-bar linkage mechanism. Thus, fingers can be controlled independently. Additionally, the parts of the gripper are three fingers, a palm, and a rotating base. The first and second phalanx is coupled and driven by the first servo. At the same time, the second motor rotates the fingers.	• It is a Multi-degree of freedom (6 DOF). • Small size. • Lightweight. • Re-configurable and flexible. • For detecting angles of motors, potentiometers are integrated. • It is capable of grasping different objects of different sizes and geometries. • They are fabricated using aluminum and a 3D printer. • Each finger is 86 mm long. • The first phalanx is 12mm in width and 33 mm long. • The second phalanx is 18 mm in width and 45 mm long. • The distance from the circumcircle to the center of the palm is 36 mm. • The total weight of the gripper is 0.827 Kg. • No force or tactile systems are present.

[23]	The aim is to create a three-fingered robotic end-effector capable of grasping different objects of different sizes, geometry, and weight.	The gripper is a three-finger gripper. The two of the fingers can rotate around the base of the gripper. The finger assembly is supported by two single-direction thrust bearings, placed on the top and bottom. The motors are placed inside the body of the fingers.	• Eight degrees of freedom. • The gripper is large in weight and size. • The entire movement of joints takes 100 ms. • Joints move 180^0 in 0.1 s. • Gripper weight is 5 kg. • Position, velocity, and force/torque are monitored using motion controllers. • The control is centralized, and it is in real-time. • Capable of grasping objects of few kilograms. • The control system is based on GUI for simplicity.
[24]	To study how can learning method can support design reconfiguration of robotic grippers for grasping using soft Omni-directional adaptation.	Three Re-configurable Omni-adaptive fingers were used to achieve grasping. Each finger is composed of an Omni-adaptive finger, an air cylinder, and a mounting structure. Through the tracheal connection, the gripper can be controlled by a solenoid valve.	• Its Omni-adaptive soft gripper with three fingers. • 96 % grasp success rate. • DeepClaw as a re-configurable robotic hardware benchmark was integrated. • Low cost. • Simple design. • Safe during a collision. • Flexible for integration. • Scalable for applications. Significant stiffness is in the longitudinal direction. • Low stiffness is in the radial direction. • Depth camera and learning method were integrated. • CNN used to train grasp planners.

(Kolluru, Valavanis and Smith, 2000), (Kolluru et al., 2000) studied The fundamentals of re-configurable Robotic Gripper system design and modeling. The design objective is to automate the limp material handling process. First, the kinematic and dynamic of the system are analyzed, and then it was validated using Integrated Design Engineering Analysis Software (I-DEAS) simulation software. This work aims to manipulate single/multiple panels without distortion, deformation, and folding, handle a load of 10 lbs, handle objects of varying shapes and sizes up to (3 ft. x 3 ft.), and integrate with commercial manipulators (AdeptOne, Adept- Three) robot arms. First, static analysis determines the likelihood of system failure due to fatigue stresses under load. Then, once the mechanism is proven statically robust, a dynamic analysis of the mechanism is performed. The static analysis includes (determining fatigue strength, yield strength torsional and bending stresses developed within the system, maximum deflections produced under the given loading conditions, and kinematic constraints.

Next, dynamic analysis has been performed to determine the system's behavior under external loads and forces. The steps involved consist of determining (natural frequency of the mechanism, effect of acceleration, dynamic displacement, resultant dynamic stresses, logarithmic decrement to determine the decay rate of oscillations due to external

disturbances).

Integrated Design Engineering Analysis Software (I-DEAS) is widely used to model, design, and Analyze mechanisms. The finite element method is used to simulate the mechanism and getting the results theoretically [3,27].

Similarly, the design and development of a re-configurable robotic gripper based on pneumatic actuation technology for grasping fabric materials are presented in (Ragunathan and Karunamoorthy's, 2006) work. Figure 3 (b) shows the gripper is a multi-degree of freedom designed to manipulate single and multiple sheets of fabric materials [28]. The design structure is similar to the design of the gripper in [25]. The gripper design and dynamic performance are analyzed in ADAMS simulation software. Likewise, For the SIMBA manipulator designed in 2016, a conceptual design for a soft re-configurable hand was presented (Mishra et al., 2017). The gripper is designed for better adaptation of the fingers to objects of different sizes and shapes. In the design of this hand, soft and hard components were integrated for both the material and the actuation. The actuation mechanism is the tendon drive mechanism, and the fingers are soft. This gripper is shown in figure 3 (d). The experimental results show that the concept and design can act in unknown and unstructured environments with robustness and reliability [29].

(Rahman et al., 2018) studied the kinematic and synthesis analysis of a modular and re-configurable gripper. Figure 3 (c) shows that the gripper can manipulate various objects consisting of four modular fingers. The finger is designed to grasp the objects firmly and release the objects according to the desired posture. The gripper can re-orientate the objects during the grasping, and then the gripper can release the object when the object's orientation is satisfied. The gripper has sixteen degrees of freedom which can be reduced according to the application. The kinematic analysis and feasibility have been expressed. The main strength of the proposed device lies in the dexterity on any given plane, reconfigurability, grasping configuration also sustaining a secure grasp. Furthermore, contact can be secured and slaughtered in different ways [30].

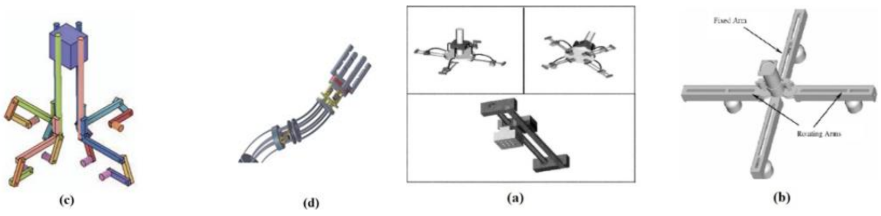


Figure 3: Four Bar-Arm/ Finger Re-Configurable Grippers.

In addition to this, for machining and part handling in smart factories, a re-configurable robotic end-effector was developed, researched, and simulated in (C.E. Reddy1 and 1, 2, 2018) work. The concept of this work is to combine a flexible gripper and a milling cutter in one compact and lightweight end-effector tool. Kinematics, dynamic finger analysis, vibration analysis of the spindle tool, and finite element analysis are performed to validate the effectiveness of the design concepts. This gripper is based on a cable-driven mechanism end-effector. The gripper part of this work can hold two, three, and four flexible multi-joint cable-driven fingers. Also, the configurability of this work provides changing between a milling cutter and part handling efficiently without changing the end effector tool. Table (3) shows more accurate parameters for the cited studies above [31].

3. MATRIX TYPE RE-CONFIGURABLE GRIPPERS

(Acaccia et al., 2004) presented the leather and fabric handling process (Limp) with a modular matrix gripper. Figure 4 (b) shows that the gripper is characterized by a modular structure based on matrix (square and hexagonal) elements and a picking module activated by an SMA spring instead of the mini electrical motors to improve overall reliability. In addition, the gripper is characterized by having multipoint grasping instead of having a fixed number of contact points, as in the case of articulated grippers [32].

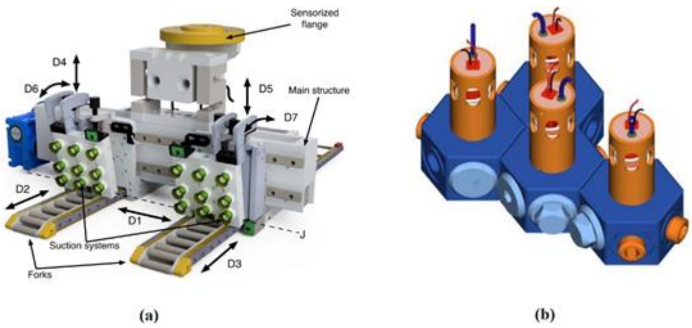


Figure 4: Matrix Type Re-Configurable Grippers.

Also, for speeding up logistics, the automatic de-palletizing process is vital to warehouses. Therefore, a flexible and adaptive gripper for robotic de-palletizing is proposed (Fontanelli et al., 2020), shown in figure 4 (a). The gripper is designed to be mounted on the end tip of an industrial manipulator. A patent-pending mechanism is used to grasp boxes and products from the top and lateral sides of the pallets. Furthermore, the gripper is re-configurable with five degrees of freedom controlled using the embedded sensors to grasp boxes of different sizes. In table (4), more details for this type of grippers are presented [33].

Table 3: The Overview of the Four Arms/Bars/ Fingers re-Configurable Grippers

Citations	Applications / Aims	The Operating Mechanism of the Fingers	Important Parameters
[3,25–27]	The gripper is used to handle and manipulate limp materials without deformation, distortion, or damage.	The robotic gripper consists of four bars in a crossbar configuration. At the end of each bar, there is a suction cup mounted for grasping limp materials. Thus, a total of four cups used for grasping each cup can translate towards the bar end and the gripper center.	• Multi-degree of freedom. • Fuzzy logic controls the amount of suction, positioning of the cups, and regulation. • Gripper mounted on AdeptOne or AdeptThree manipulator. • Robust, reliable, and accurate. • It is simulated using Matlab. • Fuzzy logic results compared to PID results. • Due to crossbar configuration, the gripper can handle a limited number of objects and shapes. • (I-DEAS) simulation software used to validate the kinematic and dynamics of the gripper. • Reliability up to 99%. • Material manipulation rate 10-12 panels/min.

[28]	It is a Pneumatic re-configurable gripper designed for grasping fabric materials in garment industries automation.	The design is consisting of four bars in crossbar configuration. Also, a suction cup is mounted on each bar for grasping. Stepper motor actuators actuate the mechanism. Each arm consists of a linear actuator in which the suction cup can linearly translate. The central arm is fixed to the center of the end effector employing corpus. Two external arms can rotate individually. With the revolute joint, the corpus is jointed with the wrist.	• Multi-degree of freedom. • Manipulate single and multiple limp sheets. • Low inertia. • High modularity. • Full flexibility. • The kinematic and dynamics of the gripper were tested by ADAMS simulation software. • Vision controller integrated. • Force/torque and position controls were integrated.
[29]	To design a soft gripper for better adaptation of objects of different sizes and shapes. It is developed for competing in the Manipulation Scenario at the RoboSoft Grand Challenge 2016.	It is Four soft fingers and an independent actuation mechanism. The fingers are connected two by two to two circular plates at 180º each other. The two circular plates can rotate using gears and a DC motor in order to reconfigure the fingers. A dc geared motor pulls the grasping mechanism actuated by the tendon for each pair of fingers. Each finger consists of three phalanges made from artificial bone and connected by tendon reinforced rubber and elastic waistband. Each finger consists of three soft joints bent by the tendon and come back by the elastic rubber property.	• Capable of lifting objects with up to 2 kg of weight. • Robust and reliable. • Flexibility. • Compliancy. • High precision and speed. • Twelve degrees of freedom.
[30]	To design a novel gripper for dexterous applications (grasp, manipulate, release).	The gripper consists of four identical modular fingers that can move in all axes. Each finger is capable of grasp, manipulating, and release the object according to the desired orientation. Thus, each finger is four degrees of freedom.	• Sixteen degrees of freedom. • Each finger has a cylindrical tip • High pair contact. • Capable of form closure manipulation. • Each finger is a five-bar linkage. • The fingertip can rotate and translate.
[31]	To research and develop a robotic gripper for machining and part handling.	The design consists of four fingers with a modular design and a machining tool; the fingers consist of a multi-link flexible joint tendon-driven finger.	• Tendon-driven gripper. • Versatile. • It is a compact and significant degree of compliance. • The spindle is designed to enhance dynamic stability. • Arduino development board used to control the design components.

4. ORIGAMI-INSPIRED RE-CONFIGURABLE GRIPPER

An origami-inspired re-configurable, adjustable suction grippers developed in (Zhakypov et al., 2018) work. The gripper in figure (5) consists of rigid, soft components driven by compact shape memory alloy actuators; the gripper can effectively self-fold into three shape modes to pick large and small flat, narrowly cylindrical, triangular, and spherical objects. In addition, the gripper is very light in weight, and it can lift loads of 50 times its weight. This gripper was compared to an under-actuated prototype for this design's versatility testing and operation method [34].

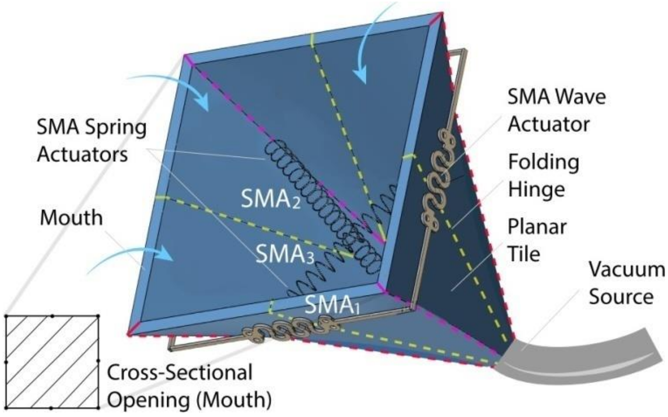


Figure 5: Origami Suction Gripper Design.

Table 4: The Overview of the Two-Finger Re-Configurable Grippers

Authors	Applications / Aims	The Operating Mechanism of the Fingers	Important Parameters
[32]	It is used for robotic handling leather and fabric materials.	The gripper is a modular matrix gripper based on innovative vacuum picking technology. The gripper is a re-shapable matrix of picking modules (points). Each picking module can be switched ON/OFF based on the shape of the template desired to be picked up.	• Multipoint grasping capability. • The picking modules are utilizing SMA actuators. • It is mechanically simpler. • It will be a high cost when the number of picking points increases.

[33]	It is used to automate and speed up the process of de-palletizing in warehouses.	The gripper comprises two extendable forks (actuated by stepper motors) that can translate linearly along a rail. The forks are coupled with two suction systems endowed with suction cups.	• Flexible and adaptive. • It is a patent-pending mechanism for grasping boxes and products from both the lateral and upper sides. • Five degrees of freedom. • It can grasp boxes with dimensions in the range of 15 to 50 cm. • It can grasp boxes with weight in the range of zero to 10 kg (four load cells). • For detecting the orientation of the boxes, sensors are embedded. • For detecting the weight, sensors are embedded. • The five degrees of freedom are actuated using three stepper motors. • For measuring the distance between the suction cups and the boxes, TOFs were utilized.

5. DISCUSSIONS

A comprehensive review has been presented in this paper on the re-configurable gripper's structure, mechanism of actuation, and essential features. In this paper, re-configurable grippers are classified according to the number of fingers. Two more types of re-configurable grippers are matrix and origami-inspired gripper types. Figure 6 shows the chart of the re-configurable gripper classes and the number of researches performed under each class. The inclusive studies from 1997 till now are 26 pieces of research. Moreover, the frequency distribution of the number of studies per year till 2021 is shown in Figure 7.

The re-configurable grippers are used for various types of applications. For example, by referring to Table 1, two-finger type grippers are primarily used in the assembly, disassembly, and grasping in unstructured environments. The structure of the fingers may be a four-bar linkage or multi-joint soft fingers and tendon-driven mechanism. Two-finger -configurable gripper's essential features are low cost, flexibility, small size, high performance, and simple control compared to other grippers. Moreover, some of these grippers are having grasping success rates from 75% up to 85%.

Further, because they have two fingers, the grasping may not be extended to hold heavy masses. Therefore, for increasing the stability of grasping and firm holding the objects, the third finger is added to the structure to support the grasping process. This case is seen in [8,10].

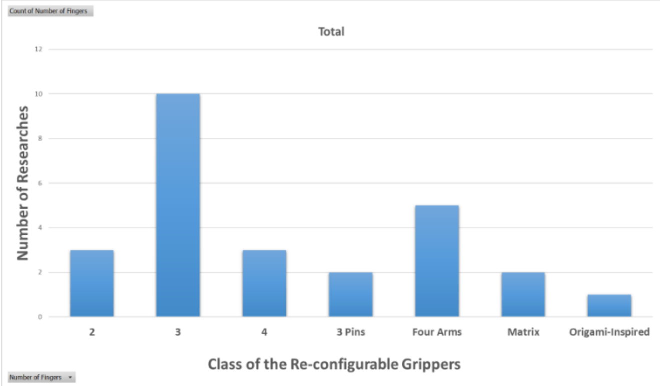


Figure 6: Shows the Number of Researches Performed under each Class of Re-Configurable Grippers.

Still, this type of gripper has the problem of grasping when the object's weight and size increase. As a result, the grasping success rate decreases dramatically, as in the case of Turco study in [10]. The maximum weight that can be grasped for this class of gripper is up to five kilograms.

For increasing the grasping problem, the gripper contact points can be increased by increasing the number of fingers. In addition, three-pin/finger re-configurable grippers are more efficient, versatile, and more dexterous. The applications of this type of re-configurable grippers are to grasp three-dimensional objects of different sizes and shapes. Also, some of these grippers are used to handle limp sheets in garment and shoe manufacturing. By referring to table 2, we can see that some grippers use the force-closure concept to grasp the objects, and some use suction cups, especially those used in handling limp materials [12,17]. Others are using electro-mechanical actuation for grasping [13]. Generally, some critical features of this class of grippers are low inertia, modularity, flexibility, adaptability, low price, multi-degree of freedom, and lightweight. In addition, some of these grippers are very lightweight, 0.827 Kg and others are up to a few kilograms in weight, 5 Kg [23,35]. Moreover, the three-finger type grippers can grasp masses from 10 grams up to 10 Kg, and others can grasp weights up to 5 Kg, [17–19].

Likewise, a multi-degree robotic four-finger, four-bar, and four-arm grippers are mentioned in table 3. These grippers are mainly used in manipulating and handling limp materials, machining, part handling, and grasping fabric and garments in industrial automation.

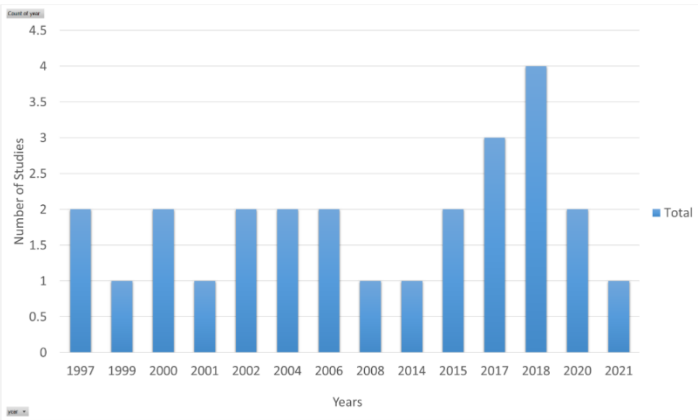


Figure 7: The Distribution Frequency of the Number of Studies per Year from 1997 to 2021.

The critical properties that describe the grippers in this class are multi-degree of freedom, robustness, reliability, accuracy, low inertia, modularity, flexibility, and high precision/speed. The design of a four-bar gripper consists of four bars in a crossbar configuration. These types of grippers can handle a limited number of objects and shapes due to their configuration. For example, suction cups are used in grasping and holding, and each bar carries a cup that can travel along the bar length, which provides reconfigurability and changes the cups' position.

Another great type of re-configurable gripper is the matrix class type. In this review, two studies introduced that developed matrix type re-configurable gripper. The grippers in this class help handle leather, fabric materials, and de-palletizing in warehouses [32,33]. This class of grippers can grasp objects of weights up to 10 Kg, and the boxes of dimensions 15 to 20 cm can be grasped. However, it is essential to mention that this type of grippers can be expensive when picking points increase.

Furthermore, an origami-inspired suction gripper is another type of re-configurable gripper. It consists of rigid and soft components actuated by memory alloy actuators. With its three shape modes, it can pick large and small cylindrical, spherical and triangular objects.

6. CONCLUSIONS

In this paper, an inclusive review is presented and tabulated in tables. The grippers in the literature are classified according to the number of fingers. The studies presented many remarkable properties, structures, and mechanisms. However, it is crucial to mention that the grippers are also suffering from many shortages besides the remarkable parameters, properties, and applications. We can summarize the conclusion using the following bullet points.

- The cable-driven grippers have the disadvantage of complexity in control.
- Vacuum and pneumatic grippers have an operational issue, high operating cost, and are not precise.
- Servo-electric-type grippers are suffering from low-force issues.
- Some grippers, as mentioned previously, can only grasp specific shapes. For example, some grippers are
- developed for grasping only cylindrical and prismatic shapes. On the other hand, other grippers are developed to grasp specific parts for the assembly of car parts.
- In the literature on this subject, the grippers can grasp weights from 10 grams up to 10 kilograms.
- Once the gripper's ability increases to grasp heavyweights, the size and weight of the gripper are increased accordingly. It can reach up to 5 Kg.
- Also, the success rate of the two-finger re-configurable gripper decreases dramatically when the weight of the object increases.
- In addition, the cost of matrix type re-configurable grippers will increase when it is required to increase the contact points.
- The multi-degree of freedom in re-configurable grippers is another problem that makes the mechanism weaker.

7. FUTURE WORK

Considering the disadvantages of the grippers mentioned in the conclusions, we aim to model and design an intelligent multi-finger and automatic re-configurable robotic gripper controller to grasp objects with different sizes and shapes based on camera vision and cloud pre-grasping algorithm. Moreover, the gripper should firm hold and safely transfer the objects grasped with a success rate of no less than 99%. The gripper should be small in size and low weight, as the capability of grasping should be no less than 10 Kg. The next study aims can be summarized in the following points.

- Design and Modeling of Multi Finger Robotic Gripper.
- The design should achieve the most astonishing dexterity, length, and clamping force required to hold the object using different control techniques and sensors.
- The design should automatically change the gripper configuration (two-finger, three-finger,four-finger).
- The controller will decide the Configuration type based on the work-piece geometry/shape.

REFERENCES

1. *Samadikhoshkho Z, Zareinia K, Janabi-Sharifi F. A Brief Review on Robotic Grippers Classifications. 2019 IEEE Canadian Conference of Electrical and Computer Engineering, CCECE 2019 2019:1–4. https://doi.org/10.1109/CCECE.2019.8861780.*
2. *Ottaviano E, Toti M, Ceccarelli M. Grasp force control in two-finger grippers with pneumatic actuation. Proceedings - IEEE International Conference on Robotics and Automation 2000;2:1976–81. https://doi.org/10.1109/robot.2000.844884.*
3. *Kolluru R, Valavanis KP, Smith SA. Design fundamentals of a re-configurable robotic gripper system - Systems, Man and Cybernetics, Part A, IEEE Transactions on. Ieee Transactions on Systems, Man, and Cybernetics 2000;30:181–7.*
4. *Nguyen VQ, Oh SB, Lim JU, Kang CH, Han SH. A study on design of three - Finger hand system. 2008 International Conference on Control, Automation and Systems, ICCAS 2008 2008:2390–3. https://doi.org/10.1109/ICCAS.2008.4694206.*
5. *Becedas J, Payo I, Feliu V. Two-flexible-fingers gripper force feedback control system for its application as end effector on a 6-DOF manipulator. IEEE Transactions on Robotics 2011;27:599–615. https://doi.org/10.1109/TRO.2011.2132850.*
6. *Vazquez J, Giacomini M, Escareno J, Rubio E, Sossa H. Optimal grasping points identification for a rotational four-fingered aerogripper. 2015 Workshop on Research, Education and Development of Unmanned Aerial Systems, RED-UAS 2015 2016:272–7. https://doi.org/10.1109/RED-UAS.2015.7441017.*
7. *Salvietti G, Hussain I, Cioncoloni D, Taddei S, Rossi S, Prattichizzo D. Compensating Hand Function in Chronic Stroke Patients Through the Robotic Sixth Finger. IEEE Transactions on Neural Systems and Rehabilitation Engineering 2017;25:142–50. https://doi.org/10.1109/TNSRE.2016.2529684.*
8. *Rosati G, Minto S, Oscari F. Design and construction of a variable-aperture gripper for flexible automated assembly. Robotics and Computer-Integrated Manufacturing 2017;48:157–66. https://doi.org/10.1016/j.rcim.2017.03.010.*
9. *Molfino R, Razzoli RP, Zoppi M. A low-cost re-configurable gripper for assembly and disassembly tasks in white industry. vol. 8. IFAC; 2006. https://doi.org/10.3182/20060906-3-it-2910.00084.*
10. *Turco E, Bo V, Pozzi M, Rizzo A, Prattichizzo D. Grasp Planning with a Soft Reconfigurable Gripper Exploiting Embedded and Environmental Constraints. IEEE Robotics and Automation Letters 2021;6:5215–22. https://doi.org/10.1109/LRA.2021.3072855.*

11. *Sudsang A, Ponce J, Srinivasa N. Grasping and in-hand manipulation: Experiments with a re-configurable gripper. Advanced Robotics 1997;12:509–33. https://doi.org/10.1163/156855397X00434.*
12. *Sudsang A, Srinivasa N, Ponce J. On Planning Immobilizing Grasps for a Re-configurable Gripper. Proceedings of the 1997 IEEE/RSJ International Conference on Intelligent Robot and Systems Innovative Robotics for Real-World Applications IROS '97 1997:106–13. https://doi.org/10.1109/IROS.1997.649016.*
13. *Cavallo E, Michelini RC, Molfino RM, Razzoli RP. Task-driven design of a re-configurable gripper for the robotic picking and handling of limp sheets. Proceedings of the International CIRP Design Seminar: Design in the New Economy 2001:79–82.*
14. *Cavallo E, Michelini RC, Molfino RM, Razzoli RP. Task-driven design of a re-configurable gripper for the robotic picking and handling of limp sheets. Proceedings of the International CIRP Design Seminar: Design in the New Economy 2001:79–82.*
15. *Yeung BHB, Mills JK. Development of a six degree-of-freedom re-configurable gripper for flexible fixtureless assembly. Proceedings - IEEE International Conference on Robotics and Automation 2002;1:888–93. https://doi.org/10.1109/robot.2002.1013469.*
16. *Yeung BHB, Mills JK. Design of a six DOF re-configurable gripper for flexible fixtureless assembly. IEEE Transactions on Systems, Man and Cybernetics Part C: Applications and Reviews 2004;34:226–35. https://doi.org/10.1109/TSMCC.2003.819704.*
17. *Ragunathan S, Karunamoorthy L. Modular re-configurable robotic gripper for limp material handling in garment industries. International Journal of Robotics and Automation 2008;23:213–9. https://doi.org/10.2316/journal.206.2008.4.206-2918.*
18. *Canali C, Cannella F, Chen F, Hauptman T, Sofia G, Caldwell DG, et al. High re-configurable robotic gripper for flexible assembly. Proceedings of the ASME Design Engineering Technical Conference 2014;5B:1–7. https://doi.org/10.1115/DETC201435245.*
19. *Canali C, Rahman N, Chen F, D'imperio M, Caldwell D, Cannella F. Theoretical and Kinematic Solution of High Reconfigurable Grasping for Industrial Manufacturing. Procedia Manufacturing 2017;11:265–74. https://doi.org/10.1016/j.promfg.2017.07.105.*
20. *Jitariu S, Staretu I. Gripper with Average Continuous Reconfigurability for Industrial Robots. Applied Mechanics and Materials 2015;811:279–83. https://doi.org/10.4028/www.scientific.net/amm.811.279.*
21. *Staretu I, Jitariu S. Reconfigurable Anthropomorphic Gripper with Three Fingers: Synthesis, Analysis, and Simulation. Applied Mechanics and Materials 2015;762:75–82. https://doi.org/10.4028/www.scientific.net/amm.762.75.*
22. *Li G, Fu C, Zhang F, Wang S. A re-configurable three-finger robotic gripper. 2015 IEEE International Conference on Information and Automation, ICIA 2015 - In Conjunction with 2015 IEEE International Conference on Automation and Logistics 2015:1556–61. https://doi.org/10.1109/ICInfA.2015.7279534.*
23. *Spiliotopoulos J, Michalos G, Makris S. A re-configurable gripper for dexterous manipulation in flexible assembly. Inventions 2018;3. https://doi.org/10.3390/inventions3010004.*
24. *Wan F, Wang H, Wu J, Liu Y, Ge S, Song C. A re-configurable design for omni-adaptive grasp learning. IEEE Robotics and Automation Letters 2020;5:4210–7. https://doi.org/10.1109/LRA.2020.2982059.*
25. *Tsourveloudis N, Kolluru R, Valavanis K, Gracanin D. Position and Suction Control of a Reconfigurable Robotic Gripper. Machine Intelligence and Robotic Control 1999;1:53–62.*
26. *Kolluru R, Valavanis KP, Smith S, Tsourveloudis N. An overview of the University of Louisiana robotic gripper system project. Transactions of the Institute of Measurement & Control 2002;24:65–84. https://doi.org/10.1191/0142331202tm050oa.*

27. *Kolluru R, Valavanis KP, Smith SA, Tsourveloudis N. Design and analysis of a re-configurable robotic gripper for limp material handling. Proceedings - IEEE International Conference on Robotics and Automation 2000;2:1988–93. https://doi.org/10.1109/robot.2000.844886.*

28. *Ragunathan S, Karunamoorthy L. Modeling and dynamic analysis of re-configurable robotic gripper system for handling fabric materials in garment industries. Journal of Advanced Manufacturing Systems 2006;5:233–54. https://doi.org/10.1142/S0219686706000820.*

29. *Mishra AK, Del Dottore E, Sadeghi A, Mondini A, Mazzolai B. SIMBA: Tendon-driven modular continuum arm with soft re-configurable gripper. Frontiers Robotics AI 2017;4:1–10. https://doi.org/10.3389/frobt.2017.00004.*

30. *Rahman N, Carbonari L, Caldwell D, Cannella F. Kinematic Analysis And Synthesis of a Novel Gripper for Dexterous Applications. Journal of Intelligent and Robotic Systems: Theory and Applications 2018;91:193–206. https://doi.org/10.1007/s10846-017-0655-x.*

31. *C.E. Reddy1 JP& GB, 1, 2 3. a Reconfigurable Robotic End Effector for Machining and Part Handling – Machine Tool. SAIIE29 Proceedings, 24th – 26th of October 2018, Spier, Stellenbosch, South Africa © 2018 SAIIE A 2018:875–88.*

32. *Acaccia GM, Bruzzone LE, Molfino RM, Zoppi M. Modular SMA-based matrix gripper for grasping and handling of limp materials. Intelligent Manipulation and Grasping IMG04 2004:266–9.*

33. *Fontanelli GA, Paduano G, Caccavale R, Arpenti P, Lippiello V, Villani L, et al. A Reconfigurable Gripper for Robotic Autonomous Depalletizing in Supermarket Logistics. IEEE Robotics and Automation Letters 2020;5:4612–7. https://doi.org/10.1109/LRA.2020.3003283.*

34. *Zhakypov Z, Heremans F, Billard A, Paik J. An origami-inspired re-configurable suction gripper for picking objects with variable shape and size. IEEE Robotics and Automation Letters 2018;3:2894–901. https://doi.org/10.1109/LRA.2018.2847403.*

35. *Su J, Qiao H, Ou Z, Liu ZY. Vision-Based Caging Grasps of Polyhedron-Like Work-pieces with a Binary Industrial Gripper. IEEE Transactions on Automation Science and Engineering 2015;12:1033–46. https://doi.org/10.1109/TASE.2014.2371852.*

36. *Deshmukh, Dinesh1 B., and Praveen Kumar Bhojane. "Design of Robotics Gripper using Cad Software and Manufacturing for Tal Brabo Robot." International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)10, Special Issue, Aug 2020, 100–105*

37. *Deshpande, Vivek, and P. M. George. "Kinematic modelling and analysis of 5 DOF robotic arm." International Journal of Robotics Research and Development (IJRRD) 4.2 (2014): 17-24.*

38. *Golshahr, Alireza, et al. "Multi wall carbon nanotube reinforced silicone for aerospace applications." Int. J. Mech. Prod. Eng. Res. Dev 8.4 (2018): 743-752.*

39. *Natarajan, S., A. Jegan, and R. Vivekananthan. "The Modelling of Contact Force of the Robot Gripper for Deformable Object using Finite Elements Method." International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) 8.6, Dec 2018, 579-588*